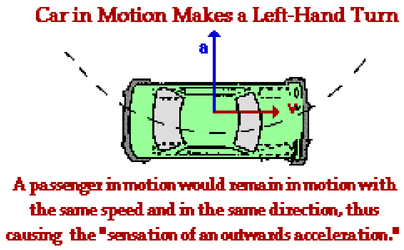
Section 3: Centripetal Force

- An object moving in a circle is accelerating.
- Even though it is moving around the perimeter of the circle with a constant speed, there is still **a change in velocity** because there is a change in direction. Thus, the object is accelerating and this acceleration is directed toward the center of the circle.
- According to **Newton's second law of motion** an object which experiences an acceleration must also be experiencing a net force; and the **direction of the net force** must be in the same **direction as the acceleration**.
- So for an object moving in a circle, there must be an inward force acting upon it in order to cause its inward acceleration. This is sometimes referred to as the **centripetal force requirement.**

Imagine you are making a left hand turn. During the turn, the car travels in a circular-type path; that is, the car sweeps out one- quarter of a circle.



The unbalanced force acting upon the wheels of the car, causes an unbalanced force upon the car and a subsequent acceleration (both of which are directed toward the center).

Your body, however, is in motion and tends to stay in motion. It is the inertia of your body - the tendency to resist a change in motion - which causes it to continue in its forward motion. While the car is accelerating inward, you continue in a straight line. If you are sitting on the passenger side of the car, then eventually the outside door of the car will hit you, as the car turns inward. This phenomenon might cause you to think that you were being accelerated outwards away from the center of the circle. In reality, you are continuing in your straight-line inertial path tangent to the circle while the car is accelerating out from under you

The sensation of an outward force and an outward acceleration is a false sensation. There is no physical object capable of pushing you outwards. You are merely experiencing the tendency of your body to continue in its path tangent to the circular path along which the car is turning.

- Any object moving in a circle (or along a circular path) experiences a **centripetal force**; that is **there must be some physical force pushing or pulling the object towards the centre of the circle**. This is the **centripetal force requirement**.

- The word "centripetal" is merely an adjective used to describe the direction of the force.

- It is NOT a new type of force but rather a **description of the direction of the net force** acting upon the object, which moves in the circle.

- Whatever the object, if it moves in a circle, there is some force acting upon it to cause it to deviate from its straight-line path, accelerate inwards and move along a circular path.

Examples

As a car makes a turn, the force of friction acting upon the turned wheels of the car provide the centripetal force required for circular motion.	**As a bucket of water is tied to a string and spun in a circle, the force of tension acting upon the bucket provides the centripetal force required for circular motion.**	**As the moon orbits the Earth, the force of gravity acting upon the moon provides the centripetal force required for circular motion.**

Because we already know Newton's Second Law to be Fnet = ma, and because in the last section we showed that for uniform circular motion $a_c = v^2 / r$, it is fairly straightforward to write Newton's Second Law to describe uniform circular motion:

substitute $a_c = \frac{v^2}{r}$ into $F_{net} = ma$ to get $F_{net} = F_c = m\frac{v^2}{r} = \frac{mv^2}{r}$

where Fc is the net centripetal force and is directed towards the center of the circular path. In other words, when a ball twirls on a string, Fc is the tension in the string.

$a_c = \frac{v^2}{r}$ and

We also know that $v = \frac{2\pi r}{T}$

Therefore, $a_c = \frac{\left(\frac{2\pi r}{T}\right)^2}{r} = \frac{4\pi^2 r}{T^2}$

And since f = 1/T, $a_c = \frac{4\pi^2 r}{T^2} = 4\pi^2 r f^2$

So, $F_C = \frac{mv^2}{r} = \frac{4m\pi^2 r}{T^2} = 4m\pi^2 r f^2$

$F_c = ma$

$F_c = m\left(\frac{4\pi^2 r}{T^2}\right)$

$F_c = m(4\pi^2 r f^2)$

From: $F_c = \frac{mv^2}{r}$

$F_c \propto m$

$F_c \propto v^2$

$F_c \propto r$

Examples:

1. Describe what would happen to the magnitude of the centripetal force acting on an object if each of the following changes were made.

a) The mass of the object is doubled.

$F = \frac{mv^2}{r}$ $F \propto m$ $F \propto (2)$ The force doubles.

b) The speed of the object is halved.

$F \propto v^2$ $F \propto (1/2)^2$ $F \propto 1/4$ The force is decreased by a factor of 4.

c) The radius of the circular path is tripled.

$F_c = m(4\pi^2 r f^2)$ $F \propto r$ $F \propto (3)$ The force is tripled.

d) The rotational frequency is quartered.

$F_c \propto f^2$ $F \propto (1/4)^2$ → $F \propto \frac{1}{16}$ Force is decreased by a factor of 16.

e) The rotational period is quadrupled.

$F_c \propto m\left(\frac{4\pi^2 r}{T^2}\right)$ $F_c \propto \frac{1}{(4)^2} \propto \frac{1}{16}$ Force is decrease[d] by a factor of [16]

f) The radius is halved and the speed is doubled.

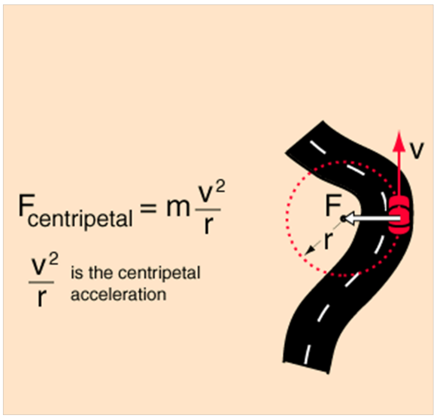
$F_c \propto v^2$ $F_c \propto (2)^2$ $F_c \propto 4$

$F_c \propto r$ $F_c \propto \frac{1}{2}$

$F_c \propto \frac{1}{2} \times 4$ $F_c \propto 2$

F_c is doubled

2. Determine the force needed to permit the 1500 kg car to round the curve, radius of 100m, if it is travelling at 100 km/hr. Where does this force come from?



3. A child on a merry-go-round is moving with a speed of 1.35 m/s when 1.20 m from the center of the merry-go-round. Calculate (a) the centripetal acceleration of the child and, (b) the net horizontal force exerted on the child (m = 25.0 kg).

3. A block with a mass of 0.153 kg is placed on a turntable which is rotating at a frequency of 1.25 Hz. The block remains at a distance of 15.1 cm from the center of the turntable without sliding off due to friction between the block and the surface of the turntable.
   Calculate the centripetal force acting on the block.

4. In a cyclotron (one type of particle accelerator), a deuteron (of atomic mass 2u) reaches a final velocity of 10% the speed of light while moving in a circular path of radius 0.48 m. The deuteron is maintained in the circular path by a magnetic force. What magnitude of force is required? ($u = 1.66 \times 10^{-27}$ kg)

5. After a day Salmon fishing, Mr. Hayter decides to feast upon a hearty 255 g Michelina Macaroni and cheese dinner. He cooks the dinner in a microwave for 3.00 minutes on a 20 cm glass dish which completes one rotation every 5 seconds.

a) Calculate the centripetal force on the dinner if it is $\frac{1}{4}$ the distance from the edge to the centre?

b) Where does the centripetal force originate?